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## Extrapolation of interaction models above LHC energies and fast simulation procedures for giant EAS

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### Abstract

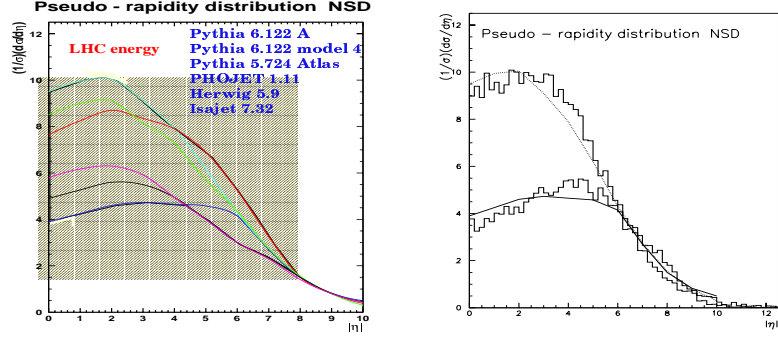
We compare models used in cosmic rays simulation to models currently used in the prospective of the LHC. EAS are simulated at the LHC energies of  $10^{17}$  eV and the different consequences on development are discussed.

### 1. Multiple production at LHC

Five years before the earliest result of the LHC at  $\sqrt{s} = 14$  TeV, the situation is comparable to our experience in the years 80's, just before the firsts result of the CERN collider.

The trajectory of the pomeron has been adapted in the QGSJet01 model the reproduction of the properties observed in cosmic rays. For this reason, we have implemented this model in CORSIKA 5.62 for a more close approach of the aspects of the giant shower expected. The actual difficulty of the extrapolation is well illustrated in Fig.1.a where we compare the pseudo rapidity distribution predicted for the LHC by a half-dozen of models currently employed in particle physics.

We underline here the wide interval expected at LHC energies, characterised by central densities of pseudo rapidity between about 3.9 (an extended plateau at the same level than the Fermi collider for Isajet) up to 9.5, with associated average charged multiplicities rising from 70 up 125. We emphasize that a comparable amplitude of the uncertainty of the predictions concerning average multiplicities and pseudo-rapidity distributions at LHC energies has been pointed out with the Dual Parton Model various assumptions on PDF ( $B_0$  and  $B_-$ ). For cosmic rays at  $10^{20}$  eV, such situation suggests an uncertainty for the value of the average charged multiplicity for p-Air collisions ranging from 250 up to 1000 secondaries. QGSJet01 model, as well as HDPM2, are in good agreement with the experimental measurements at collider energies. histograms corresponds to a As Pythia 6.122A and Isajet appears respectively as the upper and lower limit for pseudo-rapidity distribution, we have elaborated a Monte Carlo genera-



**Fig. 1. a:** the 6 full lines taken from the top represent the prediction for the LHC at  $\sqrt{s} = 14$  TeV, and the grey part represents the incertitude of high energies's models; **1.b:** upper (Pythia 6.122A) and lower (Isajet) limit for pseudo-rapidity distribution.

tor reproducing both models (fig.1.b). From the 200 collisions generated in each histogram, we have derived the most important characteristics of the collisions (average, multiplicity, inelasticity for charged and neutrals, respective distributions,  $P_t$  distribution, correlation between  $\langle P_t \rangle$  and central rapidity densities.

**Table 1.** Multiplicity and total inelasticity for QGSJet, Pythia 6.122A, Isajet at  $\sqrt{s} = 14$ TeV.

| model         | $n_{ch}$ | $K_{Tot}$ |
|---------------|----------|-----------|
| Isajet        | 70       | 0.85      |
| Pythia 6.122A | 125      | 0.696     |
| QGSJet        | 87.6     | 0.7       |

It appears that the predictions of the QGSJet model implemented in CORSIKA (ostapchenko 2001) are inserted in those limits (Table 1.): however the internal parameters of each model can be different from table 1. relating the results of the most common combinations. For instance, QGSJet tuned here with semihard treatments for string and distributions ( $\alpha_{part} = 0.5$ ), lead to multiplicity  $n_{ch} = 62.9$  ( $\alpha_{part} = 0.9$  and minijets).

This rapid overview is just an incomplete illustration of the complexity of the problem just for the most common NSD component: further considerations are needed for the SD and double diffractive component, and also for the semi-inclusive data.

Models in progress, such as Nexus which is a complex description of A-A collisions based on Gribov-Regge theory, will be probably very useful as far as the technical problems of cutting an impressive number of Pomerons will be technically solved at LHC energy.

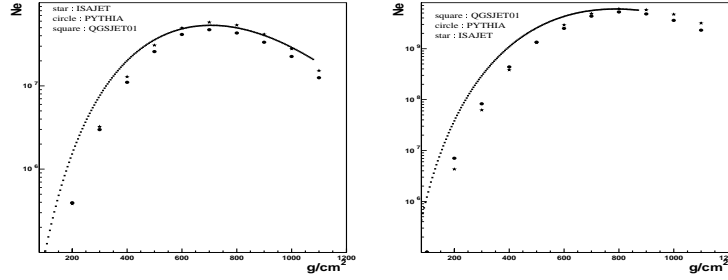
## 2. EAS simulated at LHC energies and exctrapolation above LHC energy

This guide lines of the Monte Carlo generators for Isajet and Pythia 6.122A have been taken as follows, respectively for multiplicity and central rapidity density.

$$n_{ch}^{Isajet} = 5.3 s^{0.137} \quad \text{and} \quad n_{ch}^{Pythia} = 1.1547 s^{0.25} \quad (1)$$

$$\frac{dn_{ch}}{d\eta}^{Isajet} = 4.1 \quad \text{if } s \geq 1800 \text{ GeV}^2 \quad \text{and} \quad \frac{dn_{ch}}{d\eta}^{Pythia} = 0.305 s^{0.176} \quad (2)$$

In spite of the wide interval of rapidity densities (fig.1.a), we obtained results after simulation with those generators implemented in CORSIKA, remaining concentrated for the longitudinal electron development (fig.2.) (the maximum depth, for instance, depends mainly of the forward part of the rapidity distribution).



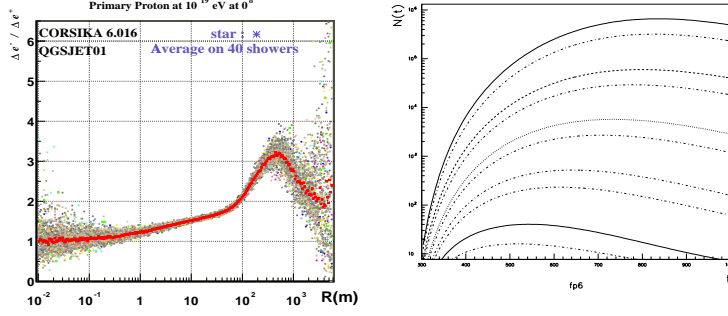
**Fig. 2. a:** Simulation at  $10^{17}$  eV for proton. The cascade curve is average on 100 showers for Isajet and Pythia, 40 showers for QGSJet. **2.b:** Simulation at  $10^{19}$  eV for proton in the same condition.

In the case of QGSJet,  $T_{max}$  is included between 679 et 723  $\text{g.cm}^{-2}$  at  $10^{17}$  eV (Ostapchenko 2001), in our case  $T_{max}$  is of 715  $\text{g.cm}^{-2}$  and 721  $\text{g.cm}^{-2}$  for Pythia and Isajet respectively.

At sea level, the corresponding electron sizes are  $2.27 \cdot 10^7$  and  $2.79 \cdot 10^7$  particles, ranging for QGSJet between  $2.75 \cdot 10^7$  (semihard,  $\alpha_{part}=0.5$ ) and  $3.5 \cdot 10^7$  (minijet,  $\alpha_{part}=0.9$ ).

For primary proton of  $10^{19}$  eV, we have simulated 40 showers for Isajet, Pythia and QGSJet (fig.2.b). The maximum depth  $T_{max}$  is respectively 822 and 844  $\text{g.cm}^{-2}$  for Pythia and Isajet, when a QGSJet gives  $T_{max}$  between 807 and 872  $\text{g.cm}^{-2}$  (os 2001).

In first approximation, the employment of QGSJet with the present state of high energy physics doesn't exhibit strong contradictions and a more detailed analysis on the muon component is now in progress.



**Fig. 3. a:** Ratio between density of electron and density of positron versus distance to the shower axis. **3.b:** Showers initiated by charged pions from 10 up to  $10^6$  GeV, with interpolation from 50 up to  $5 \cdot 10^5$  GeV (CORSIKA+EGS).

We show on fig.3. the ratios of  $e^+/e^-$  densities versus distance, obtained with CORSIKA QGSJet, as an example extracted from our important data on the 4D development.

### 3. Fast simulation for giant arrays

In order to simulate in a short time several  $10^5$  showers triggering the giant array, we have developed the code STAR (Shower Testing array Registration). Firstly, we build a library of showers initiated by charged pions or kaons, starting at different depth and different energies (fig.3.b). A fast simulation code simulate the hadron cascade and the EAS for  $E_H \geq 2 \cdot 10^6$  GeV. Under those energies, the results are interpolated in the library for any hadron of energy  $E_h$  appearing at depth  $t_0$ . Groups of 200 showers are simulated at  $10^{18}$ ,  $10^{19}$ ,  $10^{20}$  eV providing  $N_e$ ,  $s$ , and corresponding distributions. The general correlation  $E_0/N_e = f(s)$  has been derived from CORSIKA as a quadratic form.

In STAR, containing a primary spectrum generator (with ankle), we generate a primary energy  $E_0$ , then a couple  $N(E_0)$ ,  $s(E_0)$  from the distributions. If the correlation is fulfilled in 5%, the couple is accepted, the axis is choosen randomly and the densities are calculated on the array. An example of trigger on Auger experiment at different energies will be given at the conference (i-e. 13 detector are triggered in average at  $2 \cdot 10^{20}$  eV against 4 detectors at 5 EeV).

### 4. References

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